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MANET에서 장치의 이동성을 고려한 클러스터 기반 P2P 알고리즘

Cluster-based P2P scheme considering node mobility in MANET

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요 약

최근 애드혹 네트워크에서의 모바일 P2P에 대한 관심이 높아지고 있다. 비록 유선 네트워크에서 P2P 알고리즘에 대한 많은 연구가 있었지만, 기존 P2P 프로토콜들은 장치의 이동성을 고려하지 않아 모바일 애드혹 네트워크(MANET, Mobile Ad-hoc Network)에 적합하지 않다. 본 연구에서는 애드혹 네트워크에서 장치의 이동성을 고려하여 클러스터 기반의 새로운 P2P 프로토콜을 제안한다. 기존의 클러스터 기반의 P2P 알고리즘에서 각 클러스터는 슈퍼피어와 슈퍼피어에 자신이 갖고 있는 파일 목록을 등록한 피어들로 구성된다. 이동성이 높은 피어들은 클러스터 간에 자주 핸드오프가 발생하고, 이로 인하여 슈퍼피어에 파일 목록을 등록하기 위한 트래픽이 많이 발생한다. 제안하는 알고리즘에서 이동성이 낮은 피어들은 기존의 클러스터 기반 P2P의 피어들과 동일하게 동작하고, 이동성이 높은 피어들은 다르게 동작한다. 즉 이동성이 높은 피어들은 새로운 클러스터에 참여시, 자신의 존재를 슈퍼피어에게 알리지만 파일 목록을 등록하지는 않으며 파일을 찾고자 할 때 우선 슈퍼피어에 등록된 파일 목록을 검색하고 만약 찾지 못하였을 경우 검색 메시지를 클러스터 내에 전파(broadcast)한다. 본 논문에서 제안 알고리즘을 수학적으로 모델링하고 P2P 트래픽과 라우팅 트래픽에 대한 분석과 최적화를 수행하였고 수학적 모델링 결과에서 제안 알고리즘의 성능이 기존의 클러스터 기반 P2P 알고리즘과 Gnutella 알고리즘에 비해 비슷하거나 더 좋음을 보였다.

Abstract

Mobile P2P protocols in ad-hoc networks have gained large attention recently. Although there has been much research on P2P algorithms for wired networks, existing P2P protocols are not suitable for mobile ad-hoc networks because they do not consider mobility of peers. This study proposes a new cluster-based P2P protocol for ad hoc networks which utilizes peer mobility. In typical cluster-based P2P algorithms, each cluster has a super peer and other peers of the cluster register their file list to the super peer. High mobility peers would cause a lot of file list registration traffic because they hand-off between clusters frequently. In the proposed scheme, while peers with low mobility behave in the same way as the peers of the typical cluster-based P2P schemes, peers with high mobility behave differently. They inform their entrance to the cluster region to the super peer but they do not register their file list to the super peer. When a peer wishes to find a file, it first searches the registered file list of the super peer and if fails, query message is broadcasted. We perform mathematical modeling, analysis and optimization of the proposed scheme regarding P2P traffic and associated routing traffic. Numerical results show that the proposed scheme performs much better than or similar to the typical cluster-based P2P scheme and flooding based Gnutella.

Key words : 클러스터(Clustering), MANET, 이동성(Mobility), 모바일(Mobile) P2P.

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Ⅰ. Introduction

Peer-to-peer services comprise the largest traffic of wired internet network. Although most of the traffic of mobile networks has been voice traffic so far, mobile internet service are expected to grow to one of the most important service of the mobile networks. Meanwhile, MANET(mobile ad-hoc networks) have gained much interest among researchers recently. However most of the researches on MANET have been focused on physical, link and network layer protocols. With respect to application services on MANET, researches on mobile P2P services in ad hoc networks have started recently.

There have been many studies on P2P schemes for wired networks. They can be categorized to structured, unstructured and hybrid P2P schemes. In structured P2P schemes, CAN [5], Chord [6] and Pastry [7] have been proposed based on distributed hash table (DHT). They can be considered as proactive P2P schemes. Query for key is resolved by routing the query to a peer storing the value matching this key. But these systems do not consider locality in network and need a lot of control traffic to resolve query. These two factors are main obstacles to adopt DHT-based P2P schemes in ad hoc networks.

In unstructured P2P schemes, reactive schemes are used. Gnutella released by AOL in 2000 was the first system implementing a fully distributed file search [4]. Queries are broadcasted to all peers. Although it requires quite much traffic, Gnutella has gained rapidly increasing popularity because of its simplicity. However, the large amount of traffic caused by message flooding makes the Gnutella not suitable for ad hoc networks.

In hybrid P2P schemes, both proactive and reactive schemes are used. For example, cluster-based P2P schemes are based on the cluster concept and classify peers into super peers and sub peers in a cluster [8]. A super peer manages its sub peers in the same cluster. The super peer maintains a table that contains the address and file list of each of their sub peers in the same cluster. Proactive schemes are used for intra-cluster P2P and reactive schemes are used for inter-cluster P2P. Cluster-based P2P schemes were devised first for wired networks but recently their application in ad hoc networks have been studied [1, 9]. However, previous studies on the cluster-based P2P schemes in ad hoc networks were mainly regarding how to select super peers. There are different ways of selecting super peers. Super peers are selected based on a greedy method [2] or based on a grid method [3]. Maximal independent set (MIS) are used to select super peers [11]. Although there have been a lot of studies regarding cluster-based routing scheme in ad hoc networks [13], studies on features and optimizations of cluster-based P2P schemes in ad hoc networks are rare.

Cluster-based P2P scheme is one of few structured P2P schemes currently available in ad hoc networks [1, 2, 9]. Although peers in ad-hoc networks have mobility characteristics, few studies on cluster-based P2P schemes have exploited this aspect effectively. A large amount of traffic is generated by registering file list information of high-mobility peers in cluster-based P2P schemes of ad hoc networks. Therefore it is necessary to reduce this control traffic induced by high-mobility nodes.

In this study, we propose a new cluster-based P2P scheme considering peer mobility in ad hoc networks. We divide peers into low-mobility group and high-mobility group. For the low mobility group in a cluster, file list information is registered in the associated super peer. For the high mobility group in a cluster, file list information is not registered and files in them are searched on-demand basis. The main difference of the proposed scheme from the typical cluster-based P2P schemes is applying reactive scheme to find files carried by high-mobility peers within a cluster. In this study we perform mathematical analysis of the proposed scheme and derive optimal parameters. Numerical results show that the proposed scheme performs much better than or similar to the typical cluster-based P2P scheme and flooding-based Gnutella.

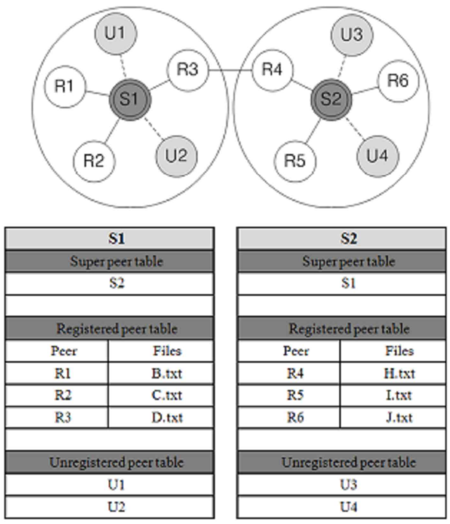

그림 1. 제안 알고리즘에서 클러스터 구조와 클러스터의 슈퍼피어가 갖고 있는 정보 테이블 구조.
Figure 1. Cluster structure and information tables maintained at the super peer of a cluster in the proposed scheme.

The remainder of this paper is organized as follows. Section 2 explains the proposed scheme in detail. Section 3 provides mathematical analysis of the proposed scheme. Section 4 gives numerical results. Finally, Section 5 gives conclusion.

Ⅱ. Proposed scheme

The proposed P2P scheme is based on the cluster-based concept. The terminology node and peer are used interchangeably in this paper. Typical cluster-based P2P scheme operates as follows [1, 8]. Peers are grouped into clusters. Each peer belongs to a cluster. A cluster consists of a super peer and registered peers. A super peer operates as a centralized server to registered peers in the same cluster. The super peer maintains the names of files which are carried by the registered peers in the same cluster. When a peer wishes to find a file, it sends a query message to its super peer. If the super peer has the information on the requested file, it sends back the information about which peer has the file. If no information regarding the requested file could be found, the super peer sends the query message to super peers in other clusters. Each super peer has a list of super peers of other clusters. The cluster concept considered in this study is an overlay network concept. Cluster-based routing concept is not assumed here and routing scheme in infrastructure network can be any scheme.

The difference of the proposed scheme from the typical cluster-based P2P scheme is as follows. In our proposed scheme, there are registered peers and unregistered peers. Registered peers register their file list to a super peer. Unregistered peers register only their existence in the cluster to a super peer not their file list. To minimize file list registration traffic, low mobility nodes are assigned to registered peers and high mobility nodes operate as unregistered peers. Therefore it is necessary to differentiate low and high mobility nodes. This can be done estimating the speed of a node and comparing it with a speed threshold. Also it is possible to select operations as registered peers or unregistered peers using cluster sojourn time as follows. When a moving peer enters a cluster region, it informs the super peer its entrance. However it waits till a certain amount of time passes before initiating a registration of its file list to the super peer. When the mobile peer moves out of the cluster region into a neighbor cluster region, it restarts its timer for registration in the new cluster area. Low mobility nodes would normally stay in a cluster region for a relatively long time and register their file list. The purpose of the proposed scheme is to reduce the possibly large amount of file list registration traffic due to frequent hand-offs between clusters by fast moving peers. Therefore in the proposed scheme, peers with high mobility generally correspond to unregistered peers and they do not register their file list to the super peer although the super peer knows their existence in the cluster.

Fig. 1 shows the information tables maintained in super peers in the proposed scheme. They are composed of super peer table, registered peer table and unregistered peer table. Super peer table contains route information to super peers of other clusters. A peer which has just powered on or enters a cluster region is registered in the unregistered peer table. This table contains only identifications of unregistered peers not the file lists of them. When an unregistered peer maintained in the unregistered peer table stays sufficient time in the cluster region, it becomes a registered peer and informs its file list to the super peer to register its file list in the registered peer table. Registered peer table contains the names of registered peers and the names of files carried by each registered peer in the cluster. When the super peer receives a registration request message from an unregistered peer, it sends back an accept message to the unregistered peer. On receipt of the accept message, the unregistered peer transmits the list of file names which it has to the super peer. When a registered peer leaves the cluster or powers down, it should send a deregistration message to the super peer and the super peer removes the peer and associated file names from the registration table.

The procedure for searching a file is as follows. When a peer wishes to find a file, it first sends a query message to its super peer. If the super peer has the file name in the registered table of itself, the super peer responds by sending the id of the peer which has the requested file. Then the searching peer would send a request message to the peer which has the file.

If the super peer does not have information about the file, it multicasts the query message to unregistered peers in the same cluster. If there is an unregistered peer that has the requested file, the peer would respond to the query message. If there is no response to the query message, the super peer would send query messages to super peers of other clusters.

When a super peer receives a query message from another super peer, the same file list search procedure is performed as described above. The super peer first searches its registered peer table and multicasts the query message to unregistered peers of its cluster if necessary. When the super peer finds the location of the requested file, it informs it to the super peer which sent the query message. This procedure is described in Fig. 2.

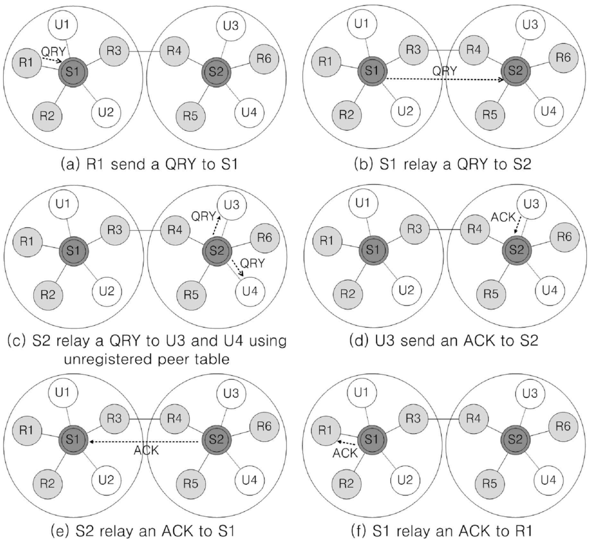

그림 2. 다른 클러스터의 비등록 피어의 파일 검색 절차.
Figure 2. Query procedure resolved by broadcasting to unregistered peers in another cluster.

It is possible to think of a variation of the search procedure described above. If a query to registered peer table fails, the super peer may have to wait sending query messages to unregistered peers until it is confirmed that every registered peer table in every other cluster does not have the corresponding file entry. By this delayed transmission of query messages, unnecessary broadcast burden could be decreased. The super peer of the cluster in which the requesting peer is located waits until sufficient time passes while receiving no message indicating the requested file match. Then the super peer broadcasts the query messages over the entire network. Although this scheme would have less broadcast load, it may cause longer latency because of the waiting time. In this paper, the first scheme is studied.

Ⅲ. Performance Analysis

The performance analysis of this study is based on [15].

3-1. Parameter Description

Important parameters used in the analysis of the proposed scheme are shown in table 1. Nodes of a network are divided into clusters. R_h is the ratio of unregistered nodes to all nodes of a cluster. When R_h is 0.0, all nodes are registered peers and when R_h is 1.0, all nodes are unregistered peers. Although the differentiation of the nodes into registered and unregistered peers in the proposed scheme is done by checking sojourn time of a peer in a cluster region, we assume that a speed threshold is used to differentiate nodes based on their speed for ease of analysis. Because high mobility nodes correspond to unregistered peers normally, this assumption can be justified. The distribution of node speed is assumed to be uniformly distributed between 0 and $V_{\max}$. We assume that the sizes of clusters are equal and the speed distribution of nodes is the same regardless of their location in a network for ease of analysis.

3-2. Analysis of P2P Control Traffic of the Proposed Scheme

P2P control traffic is mainly composed of file registration traffic and file search traffic. They are analyzed here with respect to the proposed scheme.

1) File Registration Traffic

When a low mobility node which has registered file list to the super peer of its cluster moves and hand-overs to another cluster, it registers its file list to the super peer of the new cluster. To derive this file registration traffic, cluster crossover rate of a low mobility node should be derived first.

When a low-mobility node enters into a new cluster region, it ideally initiates its file registration procedure. Therefore, normal file registration message is sent from boundary of a cluster to the super peer of the cluster which is located at the center of the cluster. The amount of the registration message traffic by which file list is registered to the super peer in the overall network is given by

표 1. 분석 파라메터.
Table 1. Analysis parameters.

Symbol	Description
N	Number of nodes in a network
N_c	Number of virtual clusters in overlay P2P network
N_i	Number of nodes in a cluster
N_l	Number of registered peers in a cluster
N_h	Number of unregistered peers in a cluster
R_l	Ratio of registered peers
R_h	Ratio of unregistered peers
r_q	File query message transmit rate per node
S_f	File list registration message size
S_q	File query message size
S_r	Routing path searching message size
P_i	Probability of the target node existing in the same cluster
H	Max. hop count from cluster's boundary to the super peer
H_a	Average hop count from a cluster node to the super peer
η_c	Cluster crossover rate of node
η_{lc}	Cluster crossover rate of registered node
R_T	Routing signaling traffic for routing path search

$$C_f = \eta_{lc} H S_f N_c. \qquad (1)$$

To send the registration message to the super peer, route to the super peer should be obtained. The routing control traffic for finding the route to the super peer is expressed as

$$C_{rf} = \eta_{lc} R_T N_c \qquad (2)$$

where R_T is routing signaling traffic necessary to find the requested routing path information and determined according to which routing scheme is used in ad hoc networks. The derivation of R_T is explained later.

2) File Search Traffic

When a querying peer sends a query message to a super peer and the target file is carried by another registered peer in the same cluster, the super peer has the information for the searched file. In this case the traffic of query message from the querying peer to the super peer is given by

$$C_{q1} = r_q P_i R_l H_a S_q N. \tag{3}$$

where $P_i R_l$ is the probability that the searched file exists in a registered peer in the same cluster. The probability that the searched file exists in the peers in the same cluster is given by

$$P_i = N_i / N = 1/N_c. \tag{4}$$

Routing control traffic associated with this file search message is given by

$$C_{rq1} = r_q P_i R_l R_T N. \tag{5}$$

When an unregistered peer in the same cluster has the requested file, the super peer does not have the information for the searched file. In this case, the super peer broadcasts the query message to all unregistered peers in the same cluster. In this case the traffic due to the query message is given by

$$C_{q2} = r_q P_i R_h (H_a S_q + N_i S_q) N. \tag{6}$$

where $P_i R_h$ is the probability that the searched file exists in an unregistered peer in the same cluster. Because the query message is broadcasted in the overlay network, it is required to find routing path to each destination unlike network layer broadcasting. The associated routing traffic is given by

$$C_{rq2} = r_q P_i R_h R_T N. \tag{7}$$

When the searched file exists in other clusters, there would be no response of finding the target file from the nodes of the same cluster. After a certain time passes without positive response, the super peer sends the query message to all super peers of other clusters. The super peers search their registered file list for the requested file. In this case the traffic of the query message is given by

$$C_{q3} = r_q (1 - P_i) R_l \{H_a S_q + (N_c - 1) 2 H S_q\} N \tag{8}$$

where $2H$ is the hop count between two adjacent super peers. Routing control traffic associated with this query message is given by

$$C_{rq3} = r_q (1 - P_i) R_l R_T N. \tag{9}$$

where it is assumed that additional routing control message is not necessary for sending messages between super peers of clusters because message transmissions between super peers occur frequently enough to maintain correct routing information always. When the super peers of other clusters could not find the target file in their registered file lists, the super peers send file query messages to all unregistered peers in their clusters. The traffic of query message is given by

$$\begin{aligned} C_{q4} &= r_q (1 - P_i) R_h \\ &\cdot \{H_a S_q + (N_c - 1)(2H + N_i) S_q\} N. \end{aligned} \tag{10}$$

Routing control traffic associated with the query message is given by

$$C_{rq4} = r_q (1 - P_i) R_h R_T N. \tag{11}$$

The total traffic of file query message is given by

$$\begin{aligned} C_q &= C_{q1} + C_{q2} + C_{q3} + C_{q4} \\ &= r_q P_i (H_a + R_h N_i) S_q N + r_q (1 - P_i) \\ &\cdot \{\mathrm{H_a} + (\mathrm{N_c} - 1) 2\mathrm{H} + \mathrm{R_h} (\mathrm{N_c} - 1) \mathrm{N_i} \mathrm{S_q}\} \mathrm{N}. \end{aligned} \tag{12}$$

The associated routing control traffic is given by

$$\begin{aligned} C_{rq} &= C_{rq1} + C_{rq2} + C_{rq3} + C_{rq4} \\ &= r_q P_i R_T N + r_q (1 - P_i) R_T N \\ &= r_q R_T N. \end{aligned} \tag{13}$$

3) Total Traffic

Total P2P signaling traffic is obtained by combining the file list registration message traffic and file query message traffic as follows:

$$\begin{aligned} C_p &= C_f + C_q \\ &= \eta_{\mathrm{lc}} H S_f N_c \\ &+ r_q P_i (H_a + R_h N_i) S_q N + r_q (1 - P_i) \\ &\cdot \{H_a + (N_c - 1) 2H + R_h (N_c - 1) N_i\} S_q N. \end{aligned} \tag{14}$$

The corresponding total routing traffic is

$$C_r = C_{rf} + C_{rq} = \eta_{lc} R_T N_c + r_q R_T N. \qquad (15)$$

The total traffic that combines the overlay P2P traffic and routing traffic is given by

$$\begin{aligned} C_t &= C_p + C_r \\ &= \eta_{lc}(HS_f + R_T)N_c \\ &+ r_q P_i (H_a S_q + R_T + R_h N_i S_q) N \\ &+ r_q (1-P_i) \begin{Bmatrix} H_a S_q + R_T \\ +(N_c - 1)2HS_q \\ +R_h (N_c - 1) N_i S_q \end{Bmatrix} N. \end{aligned} \qquad (16)$$

Ⅳ. Numerical Results

Default parameter values in the numerical evaluation of the proposed scheme are shown in Table 2. The number of total nodes of the network is set to 2000. Radius of 1-hop transmission is set to 120 m. Node density d_n is obtained by assuming 8 nodes within a circle with radius 120 m. The speed distribution of nodes is uniform distributed with maximum speed of 20 m/sec. The average size of the file list registration message is assumed to be 89612 byte which is determined by adding default header size 12 byte with the length of a file name, 128 byte multiplied by an assumed number of files maintained by a node, 700. Default file query message size is 140 byte which is header size 12 byte plus searched file name size 128 byte. In addition, file query message stores 4 byte routing information per each node as it is forwarded through nodes for file search. The size of the reactive routing message is header size 12 byte plus 4 byte per each node added. Parameter values for messages sizes are basically from [8]. Parameters to be optimized in the proposed scheme are the ratio of unregistered nodes, R_h and the number of clusters, N_c. If not stated otherwise, the optimal values of them are obtained and applied.

In Fig. 3, P2P file list registration traffic, file search traffic and reactive routing traffic and total combined traffic are drawn with respect to the ratio of unregistered peers, R_h. As R_h increases, more nodes become unregistered peers. Therefore, file registration traffic decreases and file search traffic increases because reactive file search traffic would increase. Routing traffic is relatively small and it decreases as the ratio increases. Because of the tradeoff relationship between decreasing file registration and routing traffic and increasing file search traffic, total traffic shows that there is the optimal R_h. The amount of difference between the increasing traffic and the decreasing traffic when R_h is 0 affects the value of optimal R_h.

표 2. 파라미터 설정.
Table 2. Parameter values.

symbol	value
N	100 ~ 4000
$V_{\max}$	20 m/sec
r_q	0.02 message/sec
S_f	89612 Byte
S_q	140+α Byte
S_r	12+α Byte

As the difference between amounts of traffics at R_h zero increases, the optimal R_h is likely to increase. If at R_h zero, the amount of file registration traffic decreases or the amount of file search traffic increases, the difference between them becomes smaller and the optimal R_h would move closer to zero.

Fig. 4 shows that there is an optimal number of clusters. When the number of clusters is small, the amount of the reactive routing traffic is quite large. When the cluster size becomes large, hop count between a node and the super peer increases resulting in a lot of routing search traffic. File registration traffic increases slowly as N_c increases. As more clusters are used, the cluster crossover rate increases causing possibly more file registration traffic but the hop count between cluster boundary and the super peer decreases compensating the above effect. File search traffic shows a fluctuation. As

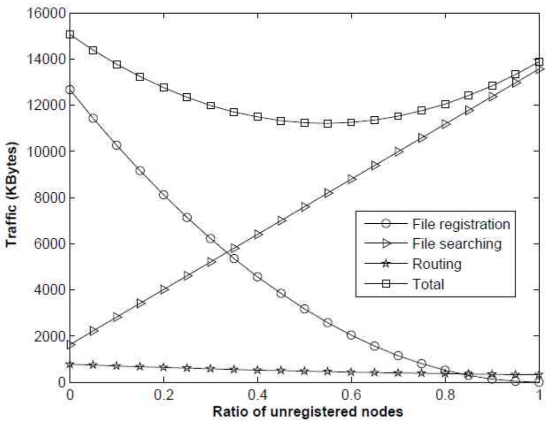

그림 3. 비등록 피어 비율에 따른 제안 알고리즘의 P2P 트래픽과 라우팅 트래픽.
Figure 3. P2P traffics and associated reactive routing traffic of the proposed scheme with respect to the ratio of unregistered peers.

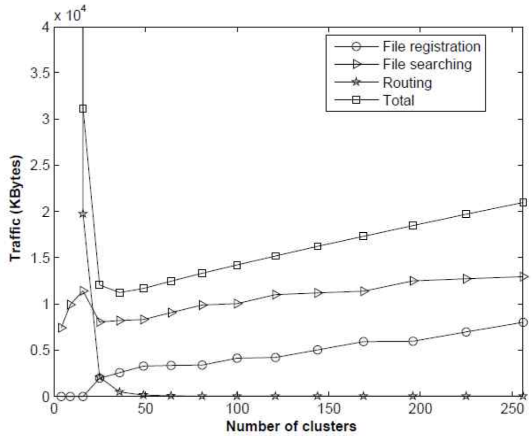

그림 4. 클러스터 수에 따른 제안 알고리즘의 P2P 트래픽과 라우팅 트래픽.
Figure 4. P2P traffics and associated reactive routing traffic of the proposed scheme with respect to the number of clusters.

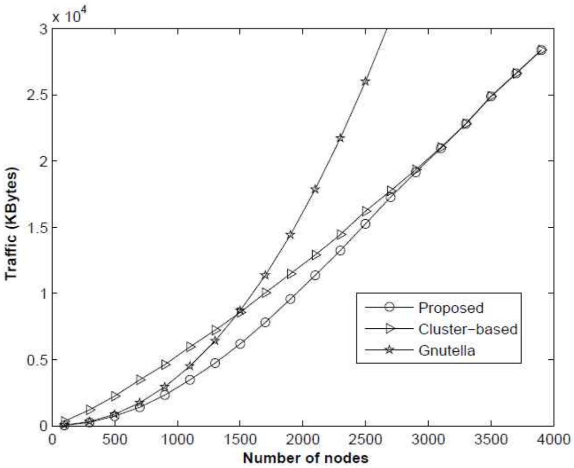

그림 5. 노드 수에 따른 다양한 P2P 알고리즘의 총 트래픽 비교.
Figure 5. Comparison of total traffic of various P2P schemes with respect to the number of nodes.

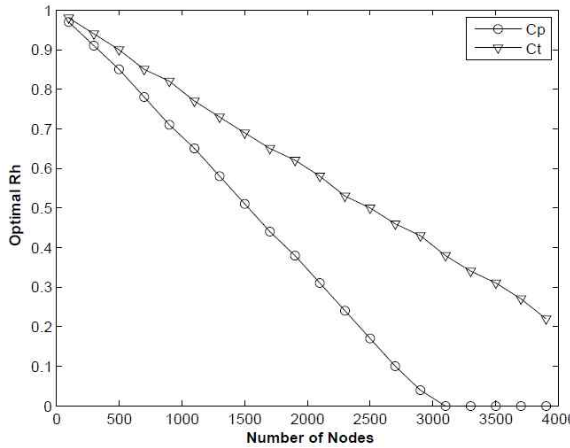

그림 6. 프로액티브와 리액티브 라우팅 알고리즘을 사용시 노드 수에 따른 제안 알고리즘의 최적 비등록 피어 비율.
Figure 6. Optimal ratio of unregistered peers of the proposed scheme with respect to the number of nodes when proactive and reactive routing schemes are used .

the number of clusters increases, the probability that a requested file exists in the same cluster decreases therefore increasing the cases of searching other clusters. Meanwhile as the number of clusters increases, the hop count between the cluster boundary and the super peer decreases and this phenomenon has the effect of reducing file search message traffic.

Fig. 5 shows that the performance of Gnutella is good when N is small but as N increases, Gnutella becomes severely inferior to the other schemes. Because Gnutella is based on flooding of file search messages, as the number of nodes increases, the amount of traffic increases exponentially. The proposed scheme shows good performance for all numbers of nodes. When the number of nodes is small, the proposed scheme shows similar performance to Gnutella and when the number of nodes is large, the propose scheme shows similar performance to the typical cluster-based scheme. In the mid range of number of nodes, the proposed scheme is the best. We can see that the proposed scheme always shows performance better than or equal to those of other schemes.

Fig. 6 shows the optimal R_h with respect to the number of nodes. C_p represents the case that proactive routing scheme is used with R_T equal to 0 and C_t is for the case that reactive routing scheme is used. When the number of nodes is small, the optimal R_h is 1 which means that the proposed scheme operates similar to Gnutella and when the number of nodes is large, the optimal R_h becomes 0 which means that the proposed scheme operates as the typical cluster-based P2P scheme. When proactive routing is used, the optimal R_h decreases faster than the case of reactive routing case. The reason is that because routing traffic decreases with increasing R_h, more routing traffic contributes to make the optimal R_h higher for the same number of nodes as explained in Fig. 3.

Ⅴ. Conclusion

We proposed a new cluster-based P2P scheme which utilizes node mobility. The proposed scheme divides nodes into low-mobility registered node group and high-mobility unregistered node group. Analysis of the proposed scheme is carried out to find the optimal parameters of the proposed scheme. Numerical results show that the proposed scheme performs better than or similar to Gnutella and the typical cluster-based scheme.

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